Perception of Gradient in Haptic Graphs: a Comparison of Virtual and Physical Stimuli

Beate Riedel & A. Mike Burton

Department of Psychology
University of Glasgow
Glasgow G12 8QQ
beate@psy.gla.ac.uk
mike@psy.gla.ac.uk

Abstract

We report an experiment in which people were asked to make a judgement about the gradient of a simple line graph. As part of the MultiVis project on data visualisation for blind people our aim was to discover how accurately linear graphs can be rendered using relatively simple technology: raised paper, and a haptic force-feedback mouse. Results show that both media allowed very accurate performance.

Introduction

This work is part of the MultiVis project (multivisualisation for the blind). The main objective of this project is to make statistical information, such as graphs and tables, more accessible to blind people. Using virtual reality technologies, it is hoped this will be achieved by using alternative forms of displaying information to the blind and the visually impaired.

Blind and visually impaired people interact with the world using auditory and tactile sensory modalities. For this reason, the project explores the use of 3D sound and virtual reality haptic presentation to render information. The focus of this study was the haptic domain, and in particular its utility for presenting information related to virtual reality line graph displays.

The Study

The aim of this study was to examine how accurate people are at processing varying gradients of simple line graphs presented as tactual lines on raised paper or as virtual haptic lines via a force-feedback mouse.

A comparison between physical and virtual reality media will allow assessment of the haptic force-feedback device. In particular, we were interested to establish whether the force-feedback mouse would provide an accurate means for presenting simple linear graphs when compared to physical raised lines (on a relief map). If it is accurate, the virtual reality device has many advantages over the physical map, particularly in the fact that the display can be changed very simply (e.g., by re-rendering information) whereas separate physical displays (relief maps) need to be constructed for each new presentation.

From the psychological perspective, there has been little research on the processing of tactile line orientation [eg 1, 3]. The patterns of results obtained from these studies generally focus on particular phenomena such as the "haptic oblique effect". This shows poorer performance in oblique linear orientations than in vertical and horizontal ones [1]. These experiments have been conducted using physical media that can be fully explored by touch. Whether haptic perception of virtual line orientations follows the same pattern as with physical media is an important question in terms of data visualisation for the blind [4, 5]. It is by no means clear that the two media will be equivalent in this regard. Virtual reality force-feedback devices are limited to a single point of contact, and do not support the direct skin contact available for physical stimuli. If virtual reality force-feedback media are to be used to render line graphs for blind people, it is important to establish whether these media are sufficiently sensitive to do so. Since line orientations in a line graph are a primary source of information, we began our investigations by asking whether people can process the gradient of a given line with such media. To investigate this question, an experiment was set up which used simple linear graphs and a forced-choice paradigm.

Experiment

20 participants were recruited for this experiment. All participants were sighted, as well as right-handed. None had any known

sensory or motor disabilities which might have affected their haptic perception.

A set of virtual, haptic stimuli was presented using Logitech's WingMan force-feedback mouse. The virtual stimuli for use with this mouse were generated using the Immersion Studio Application (version 3.4.2) software.

Another set of stimuli was presented on raised paper (swell paper). This allows the photocopying of stimuli onto special paper, which is then put through a HotSpot machine raising the darkened areas through a heating process, and producing a relief map.

For the virtual, haptic stimuli a set of 68 virtual lines was generated. These consisted of four replications each of a set of angled, virtual lines taking a horizontal orientation (0^o) as reference point. This formed the basis for producing virtual lines at stepwise angular increases of 3^o each, both sloping up and down from the horizontal, up to 24^o either side of the horizontal. This generated a set of virtual, angled lines at the following angles (taken from the horizontal): 3^o, 6^o, 9^o, 12^o, 15^o, 18^o, 21^o, 24^o (all sloping up), -3^o, -6^o, -9^o, -12^o, -15^o, -18^o, -21^o, -24^o (all sloping down) and 0^o (horizontal). Furthermore, four virtual haptic practice lines were generated consisting of 2 x 30^o (upwards) and 2 x -30^o (downwards) angled lines.

Generating the virtual lines themselves was accomplished using the *Enclosure Effect* within the *Position Based Effect* which is supplied with the Immersion Studio software. This Enclosure Effect gives the impression of a haptic line which is determined by four walls as boundaries. In this way, participants haptically perceive a line as an engraved groove. Pilot studies had shown that an "engraved" effect was easier for subjects to use than a "raised" effect. The latter, though approximating more closely to a raised-paper line, tended to allow subjects to lose the region of interest by "falling off" the line [5]. Stiffness and saturation for all stimuli was set to 10,000 units for left/right and top/bottom walls. Thickness of these was set to 25 units. A stiffness mask was activated for each stimulus pertaining to 'In_Top', 'In_Bottom', 'In_Left' and 'In_Right'. The centre width of each line (ie enclosure) was set to 500 units for width and 50 units for height. For each virtual line boundary coordinates were variable as were the centre settings for both the x and y coordinates. All lines were presented to participants in the centre of the haptic display field of the force-feedback mouse. The strength of the force-feedback was set to maximum strength throughout.

The haptic 'viewing' field in which the force-feedback mouse operates was 4cm x 3.5cm in size.

For the raised paper lines the same set of 68 angled lines and four practice lines as for the virtual stimuli was created. Lines for these stimuli measured 9.7cm in length and .5cm in width. Raised line stimuli were presented to participants in a styropor foam frame. This allowed participants to feel the stimuli themselves, as well as the boundaries set by the frame. The overall frame size measured 37.5cm x 25.5cm. The haptic 'viewing' field measured 13.5cm x 9.8cm.

Design and Procedure

There were two conditions in this experiment: raised lines and virtual lines. The presentation of the two conditions was blocked and the order of presentation for these counterbalanced. Participants were randomly allocated to the presentation order of the two conditions and were blindfolded throughout the experiment. They were presented with the linear graphs, and asked to say whether the gradient was positive or negative (sloping upwards or downwards from left to right). They were instructed to guess if they were unsure of the direction of a gradient.

For each virtual line the mouse's cursor was positioned on the line's centre. The mouse itself was positioned straight on its fixed pad and placed in front of participants. In the virtual lines condition participants were firstly familiarised with the mouse and its force-feedback by letting them explore two demonstration files supplied with the WingMan utilities, FEELitObjects.

For the raised paper lines, the styropor frame was fixed in front of participants.

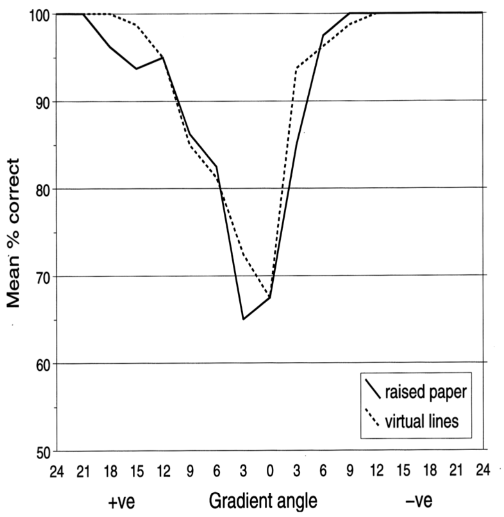
Once a given line was set up for presentation, participants moved their own hand into position to feel it. In order to reflect real world users' variability in exploring objects tactually, participants were allowed to explore the lines in any manner they wished, employing any strategy they wanted. They were also allowed to explore each line without time limit.

Participants were given four practice stimuli for each condition.

Results

The percentage of correct responses for both the raised lines (swell paper) and virtual lines (force-feedback mouse) can be seen in Figure 1.

Figure 1. Participants' responses to raised and virtual lines.



Statistical analysis was conducted on data from –9 to +9 degrees, as inspection showed ceiling effects beyond this range. Within this range, there was a very large effect of angle, reflecting a drop in performance as the angle became shallower (F6, 114) = 10.5; $p < 0.05$). There was no significant interaction (F(6, 114) < 1) reflecting the fact that decreasing angles affected both presentation media equally.

In the case of zero degrees, participants did not behave at random, but exhibited a bias towards responding "downwards". This bias was significant across the groups (single sample t-test, $t(19) = 4.3$; $p < 0.05$) and equivalent for each.

These results show that both media allowed highly accurate performance, and that the pattern of errors appears to be equivalent across each.

Discussion and Conclusion

First, we note that subjects were very accurate at this task. Within roughly 6 degrees of the horizontal they perform at ceiling levels. Even within 3 degrees of the horizontal, performance is very good. Second, we note that the pattern of accuracy and errors appears to be very similar across the two media. This is perhaps surprising, because the physical raised-paper appears to offer richer information. Interacting with a physical object, subjects can use both tactile and haptic cues, whereas the force-feedback mouse allows only a point-haptic interaction.

The pattern of results observed in this study supports the use of virtual reality haptic media in the rendering of line graphs for blind people. Although employing blindfolded participants, there is no reason to suggest the pattern of results should be different for blind people. The basic psychological processes required to make gradient decisions on differently sloping simple line graphs should be the same for seeing and blind people.

Furthermore, the degree of accuracy in making gradient decisions in both media is encouraging in regards to the use of this form of information rendering for statistical data such as line graphs for the blind.

An experiment is currently in progress to expand the present study to the use of the PHANToM force-feedback device. This experiment investigates whether the orientation of the presentation plane (ie horizontal vs vertical) has an effect on perception of line gradient, since each plane presents a different context of gravitational cues [2].

We conclude that the haptic mouse allows very accurate rendering of simple line graphs.

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